Cardiac Problem Solving: Imaging the Coronary Arteries in 2006: Head-to-Head Comparison of MDCT and MRCA

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Introduction

Invasive coronary angiography is the reference to make the diagnosis of coronary artery disease (CAD) and to orient the treatment strategy. Although coronary angiography is a very effective diagnostic tool, it clearly is an invasive procedure that bears substantial morbidity (1.5%) and mortality (0.15%) risks, as well as important costs. Ideally thus, coronary angiograms should only be performed in selected patients in whom the diagnosis of CAD has already been established noninvasively and for whom the choice of treatment depends on coronary anatomy. Yet, despite continuous refinements in the noninvasive detection of CAD, a significant number of patients undergoing diagnostic coronary angiography still show no or minimal CAD. Thus there is a real need for better selection of patients to undergo diagnostic coronary angiography. For this purpose non-invasive coronary imaging techniques might play an important role.

Techniques

The non-invasive imaging of the coronary arteries is made difficult by the small size of these arteries and their complex cardiac and respiratory motion. Recently, 2 imaging modalities, MR coronary angiography and Multi-detector CT, have emerged as plausible candidates for the noninvasive visualization of the coronary arteries. The two techniques not only rely on different physical principles to image the coronary arteries, but also differ in the way they compensate for cardiac and respiratory motion (Table 1).

Table 1. Major differences between MRCA and MDCT.

	MRCA	MDCT		
		4 slice	16 slice	64 slice
Cardiac motion correction	Prospective	Retrospective		
Respiratory Motion Correction	Free-Breathing Navigator	Breathhold		
Duration of Acquisition	20-30 min	40-50 sec	20 sec	10 sec
Contrast	0	140 ml	100 ml	60 ml
Radiation dose	0	8 mSv	10-12 mSv	12-16 mSv
Temporal resolution	Variable	250 ms	105 ms	90 ms
Spatial resolution	1 x 1 x 1.5 mm	0.8 x 0.8 x 1.2 mm	0.7 x 0.7 x 0.8 mm	0.5x0.5x0.5 mm

Magnetic Resonance Coronary Angiography (MRCA)

MRCA has emerged in the early 1990, however only recent technical improvements in have allowed clinically use on larger scale. Initial MRCA studies employed bright-blood turbo-gradient-echo (TGE) pulse sequences[1]. More recently, MRCA steady state fast field (SSFP) pulse sequences[2] have been developed, resulting in higher image quality. Visualization of coronary arteries vs adjacent structures such as muscle, venous blood and pericardial fat can be improved by selectively suppressing signal from these adjacent structures by use of T2 prep pulses and fat-saturation pre-pulses. Therefore, MRCA in opposition to MDCT allows the visualization of coronary arteries by use of only intrinsic tissue signal and does thus not require any injection of contrast agents. Cardiac motion correction in MRCA is performed by prospectively triggering image acquisition to an ECG or vectocardiographic gating signal. The temporal resolution of most sequences can be adapted by modifying the number of shots per heart beat. If the number of shots per heart beat is decreased, temporal resolution improves, however overall image acquisition duration increases, as more heart beats are required to fill up K-space. The most recent reports suggest to individually adapt temporal resolution and imaging delay to the time of coronary diastasis of the patient by measuring his period of coronary diastasis on a cine scout. Because patients which low heart rate have longer periods of diastasis, imaging efficiency can thus be increased in such patients by lengthening temporal resolution of imaging. On the other hand, in patients with high heart rate, temporal resolution may need to be shortened to reduce motion artifacts and accommodate for faster coronary motion. The small size of the coronary arteries requires that MRCA is performed in 3D imaging modes with high imaging matrices. The duration of such image acquisitions exceeds the breathhold capabilities of patients. Therefore most recent MRCA pulse sequences employ free breathing diaphragmatic navigator gating[3] for respiratory motion compensation. A limitation of this approach is that navigator drift may occur, resulting in poor gating efficiency. Several techniques, for drift correction are currently developed to overcome this shortcoming. The most significant improvement to MRCA has been development of whole-heart imaging[4]. In this approach a single axial prescription covering the entire heart is acquired, instead of individually prescribing multiple directional for individual coronary arteries using localizer scouts. This approach significantly simplified the difficult localizing and prescription phase of MRCA which used to be extremely time consuming and which used to require a lot of user experience. In addition it allows better visualization of smaller branch vessels than the directional approach. However, similar to MDCT, whole-heart MRCA requires postprocessing of the 3D stack with specific post-processing tools to reveal the coronary arteries. The use of whole heart imaging has allowed to significantly speeding up imaging. Indeed typical acquisition duration of MRCA with whole heart imaging can be performed in 20 to 30 minutes vs. more than 50-60 minutes were required to perform MRCA when coronary arteries were individually localized and prescribed. Presently, the most important challenge of MRCA remains limited signal to noise. This limitation currently confines spatial resolution of acquired voxels to about 1x1x1.5 mm^3, preventing submillimeter imaging, as theoretically required for imaging the small vessel lumen of coronary arteries. It remains unknown if the increased signal of recent 3T systems can be used to overcome this limitation and to improve spatial resolution and acquisition of smaller voxel size.

Multi-detector Row CT(MDCT)

Cardiac MDCT has only emerged about 5 years ago, but has undergone very rapid development over the last few years(5). Cardiac MDCT is performed by combining multidetector acquisition with a low table advancement pitch, so that the acquired emission data of the different detectors acquire several overlapping slices at the same Z position(6). An ECG signal is recorded together with the data acquisition and the data is corrected for cardiac motion by retrospective rearrangement of multisection partial scan data in relation to the cardiac cycle. Typically coronary images are reconstructed only by using data from end-diastole. Respiratory motion artifacts are prevented by acquiring the data during breath holds. The most important improvement of MDCT has been the increase in detector rows: In the first generation of scanners only 4 detector rows were employed, the second generation employed 16 detector rows and the most recent 3rd generation of systems 40-64 detector rows. The increasing number of detector rows and the increase of tube rotation speed of newer systems, has allowed to significantly improve temporal resolution (from about 250 ms to currently approximately 90 ms), significantly reducing the number of motion artifacts, that were often present in the first generation of systems. In addition the larger coverage of 16 and 64 detector row systems has allowed reducing scanning time and thus breathhold duration from approximately 50 seconds for 4 detector row systems to currently about 10 seconds for the most recent 64 detector row systems. The major advantage of MDCT over MRCA is significantly higher signal to noise ratio. Therefore it allows for acquisition of significantly smaller voxels (0.5 x 0.5 x 0.5 mm^3 for the most recent 64 slice systems) than MRCA. In addition, the reconstructed voxels of MDCT are also more isotropic than those of MRCA favoring better 3D reformatting. Given that absorption rates are constant and known for different tissues, postprocessing can be performed more easily and more automatically on MDCT than on MRCA images, where signal intensity is arbitrary and variable from one patient to another. As compared to MRCA, MDCT excels in simplicity, acquisition speed, image quality and robustness. Yet its most significant limitation remains its high radiation exposure. Because the more recent generations of scanners employ higher tube currents, this dose has actually increased and presently averages around 12-16 mSv, thus 3-4 times more than invasive coronary angiography. While dose-modulation schemes, with reduction of tube current in systole, have been developed, reduction of dose exposure is at best 40%. Another limitation of MDCT is that differentiation between the coronary arteries and the adjacent tissue requires the intravenous injection of an iodated contrast agent, which may be potentially nephrotoxic and allergenic. Fortunately because of shorter acquisition duration, the quantity of contrast needed for coronary imaging has decreased from about 120-140 cc for the first generation of 4 detector row systems to approximately 60 cc for the most recent generation of 64 slice systems. Another limitation of MDCT remains that because of its limited temporal resolution and retrospective gating algorithm, patients with high heart rate and cardiac arythmias present motion artifacts. Lowering heart rate by premedication with beta-blockers is required to lower heart rate to less than 70 bpm, however, MDCT can not be employed in patients with constant arrhythmia, such as atrial fibrillation.

Diagnostic Accuracy for Detection of Coronary Artery Disease.

Magnetic Resonance Coronary Angiography

A summary of the most recent trials which evaluated the diagnostic accuracy of MRCA vs. conventional invasive angiography is shown in Table 2. The recent technical improvements have allowed to significantly improve diagnostic accuracy and to increase the number of segments to be interpreted. Indeed in the multicenter trial(1) performed in 109 patients using the 3D free-breathing Turbo-Gradient Echo with directional imaging only proximal and middle segments could be evaluated. Overall 84% of those segments were found to be interpretable. In these segments, sensitivity was high (93%) however, specificity was low (42%). Diagnostic accuracy was better for 3 vessel and left main disease than for single vessel disease. More recent studies using SSFP directional technique(2,7) improved image quality and allowed evaluation of also smaller distal segments. Also with these more recent studies, specificity was found to be improved. The most recent whole-heart MRCA technique was evaluated in two recent studies published this year. The whole-heart approach(8,9) appears to allow interpretation of the highest number of coronary segments. Indeed in contrast to directional techniques it also allowed visualization and interpretation of branch vessels such as marginal or diagonals. The diagnostic accuracy of these whole heart imaging studies was also higher than that of directional techniques with individual localization of coronary arteries. Sensitivities between 78 and 82% and specificities of 91% were reported.

Table 2. Diagnostic Accuracies of recent MRCA trials

Investigator	# of pts	Method	% evaluable	Sensitivity	Specificity
Kim (*NEJM 2001*)	109	3D-TGE DIR-NAV	84%	93%	42%
Bogaert (*Radiology 2003)*	21	3D-SSFP DIR-NAV	71%	44-55%	84-95%
Sommer (*Radiology 2005)*	18	3D-SSFP DIR-NAV	86%	82%	88%
Jahnke (*Eur Heart J 2005*)	55	3D-SSFP WH-NAV	83%	78%	91%
Sakuma (*Radiology 2005*)	38	3D-SSFP WH-NAV	92%	82%	91%
All	241		84%	84%	69%

TGE: Turbo-Gradient-Echo, SSFP: Steady-State-Free-Precession, DIR: Directional, WH: Whole-Heart, NAV: Navigator Gating.

Multi-detector Row CT

Many more studies have compared MDCT vs conventional invasive coronary angiography with very encouraging reports(5) (Table 3). The first generation of 4 slice MDCT scanners, allowed approximately 66-82% (on average 68%) of segments to be evaluated. In evaluable segments, sensitivities ranged between 66 and 91% (on average 85%) and specificity was high ranging between 84-99% (on average 97%) to detect

Table 3. Diagnostic Accuracies of 4, 16 and 64 slice MDCT trials

4 slice MDCT

Investigator	# of pts	% evaluable Segments	Sensitivity evaluable segments	Sensitivity all segments	Specificity
Achenberg (2001)	64	68%	91%	58%	84%
Nieman (2001)	35	73%	81%	-	97%
Vogl (2002)	64	66%	73%	-	99%
Giesler (2002)	100	71%	91%	49%	89%
Kopp (2002)	102	82%	93%	90%	96%
Kuettner (2002)	66	69%	66%	37%	99%
	431	68%	**85%**	**69%**	**97%**

16 slice MDCT

Investigator	# of pts	% evaluable Segments	Sensitivity evaluable segments	Sensitivity All segments	Specificity
Nieman (*Circ 2002*)	59	100%	95%	95%	86%
Ropers (*Circ 2003*)	77	88 %	92%	73%	93%
Kuettner (*JACC 2004*)	60	100%	72%	72%	97%
Kuettner (*JACC 2005*)	124	100%	85%	85%	98%
Mollet (*JACC 2004*)	128	100%	92%	92%	95%
Hoffmann (*Circ 2004*)	33	83%	82%	63%	94%
Heuschmid (*Int J Cardiol 2005*)	37	78%	93%	59%	87%
Hoffmann (*JAMA 2005*)	103	88%	95%	-	98%
Achenbach (*Eur Heart J 2005*)	50	96%	94%	93%	96%
All	568	96%	**88%**	**82%**	**94%**

64 slice MDCT

Investigator	# of pts	% evaluable Segments	Sensitivity evaluable segments	Sensitivity All segments	Specificity
Leber (*JACC 2005*)	59	93%	79%	-	97%
Raff (*JACC 2005*)	70	88%	95%	-	86%
Leschka (*Eur Heart J 2005*)	67	100%	94%	94%	97%
Mollet (*Circ 2005*)	52	100%	97%	97%	95%
Pugliese (*Eur Rad 2005*)	35	100%	99%	99%	96%
All	283	96%	**92%**		**94%**

coronary stenosis. Sensitivity was however much lower (37-90%, on average 69%), if non-evaluable coronary segments were not excluded. The major limitation of this first generation of 4 slice MDCT was related to its low temporal resolution of 250 ms. Because of this low temporal resolution, motion artifacts were often present, especially

on the right coronary artery, which presents the fastest motion during the cardiac cycle. In addition, because of limited spatial resolution, segments with severe calcification were also found to be difficult to evaluate.
Results of the second generation of 16 slice MDCT scanner were significantly better than 4 slice MDCT. Indeed because of higher temporal and spatial resolution, artifacts were reduced and the number of evaluable segments was found to be much higher (on average 96%) than with 4 slice MDCT. Overall sensitivity (88%) and specificity (94%) was significantly increased.
The latest generation of 64 slice MDCT systems(10,11,12,13,14) has even better image quality allowing interpretation of still smaller coronary segments. According to the first reports, 64 slice MDCT appears to have even higher sensitivity (92%) and specificity (94%) than the already high diagnostic accuracies of 16 slice MDCT.

Head to head comparison of MDCT and MRCA

Only two studies have directly performed direct head to head comparison of MRCA vs MDCT. The first study compared 4 slice MDCT vs 3D SSFP directional MRCA(15). In this study in 27 patients, MDCT was found to have higher sensitivity (79% vs 62% $p<0.05$) of segments with significant stenosis, but lower specificity (71% vs 84%, $p<0.001$) for exclusion of segmental coronary artery stenosis. The overall diagnostic accuracy of MR imaging (80%) was significantly higher than that of CT (73% $P < .05$).
In a subsequent study comparing 16 slice MDCT against MRCA in 50 patients(16), MR and MDCT had similar sensitivity (75% vs. 82%, p = NS), specificity (77% vs. 79%, p = NS), and diagnostic accuracy (77%, vs. 80%, p = NS) for detection of >50 % DS if analysis was performed visually. Quantitative analysis allowed to significantly improve the diagnostic accuracy of MDCT but not that of MR. Up to today no direct comparison of 64 slice MDCT and whole heart MRCA has been performed,

Summary and Recommendations

Both MDCT and MRCA are useful for the non-invasive detection of coronary artery stenoses. Because neither technique is 100% accurate, these techniques are not ready yet to replace conventional coronary angiography. However, because of their high negative predictive values, both tests could be useful to better select patients who should not be referred to conventional X-ray angiography, thereby avoiding the performance of unnecessary normal coronary angiograms. In particular, these tests might be useful to better select whether patients with intermediate clinical probability of coronary artery disease should undergo invasive coronary angiography. They might also be useful in patients where other non-invasive exams perform poorly, such as in patients with resting ECG abnormalities, and in those unable to exercise.
The most recent studies seem to slightly favor MDCT over MRCA. Indeed 64 slice MDCT currently allows better image quality, is easier to perform, robuster and tends to have higher diagnostic accuracy in separate trials than MRCA. Yet in direct head-to-head comparison 16 slice MDCT and MRCA performed equally well.
The choice of which test to use, should probably depend on individual patient characteristics and operator experience. MDCT would probably be the first choice in the large majority of patients, yet has the disadvantage of requiring contrast injection and of exposing patients to potentially harmful radiation. MRCA could be a safe alternative in

patients with known allergies to contrast agents and those at risk for renal insufficiency after contrast agent administration. MRCA however is contraindicated in patients with pacemakers and in those suffering from claustrophobia.
Since the field of noninvasive coronary imaging is still rapidly evolving, we anticipate that upcoming improvements will result in additional increases in the diagnostic accuracy of both imaging techniques.

References

1. Kim, W. Y. Coronary magnetic resonance angiography for the detection of coronary stenoses. N.Engl.J.Med.: 2001;345;1863

2. Bogaert, J. Coronary artery imaging with real-time navigator three-dimensional turbo-field-echo MR coronary angiography: initial experience. Radiology: 2003;226;707

3. Stuber, M. Double-oblique free-breathing high resolution three-dimensional coronary magnetic resonance angiography. J Am Coll Cardiol: 1999;34;524

4. Weber, O. M. Whole-heart steady-state free precession coronary artery magnetic resonance angiography. Magn Reson.Med.: 2003;50;1223

5. Budoff, M. J. Clinical utility of computed tomography and magnetic resonance techniques for noninvasive coronary angiography. J.Am.Coll.Cardiol.: 2003;42;1867

6. Ohnesorge, B. Cardiac imaging by means of electrocardiographically gated multisection spiral CT: initial experience. Radiology: 2000;217;564

7. Sommer, T. Coronary MR angiography at 3.0 T versus that at 1.5 T: initial results in patients suspected of having coronary artery disease. Radiology: 2005;234;718

8. Sakuma, H. Assessment of coronary arteries with total study time of less than 30 minutes by using whole-heart coronary MR angiography. Radiology: 2005;237;316

9. Jahnke, C. Rapid and complete coronary arterial tree visualization with magnetic resonance imaging: feasibility and diagnostic performance. Eur.Heart J.: 2005;26;2313

10. Leber, A. W. Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol: 2005;46;147

11. Raff, G. L. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol: 2005;46;552

12. Pugliese, F. Diagnostic accuracy of non-invasive 64-slice CT coronary angiography in patients with stable angina pectoris. Eur.Radiol.: 2005;1

13. Mollet, N. R. High-resolution spiral computed tomography coronary angiography in patients referred for diagnostic conventional coronary angiography. Circulation: 2005;112;2318

14. Leschka, S. Accuracy of MSCT coronary angiography with 64-slice technology: first experience. Eur.Heart J: 2005;26;1482

15. Gerber, B. L. Coronary Artery Stenosis: Direct Comparison of Four-Section Multi-Detector Row CT and 3D Navigator MR Imaging for Detection--Initial Results. Radiology: 2005;234;98

16. Kefer, J. Head to head comparison of Multislice Coronary CT and 3D Navigator MRI for the detection of coronary artery stenosis. J Am Coll Cardiol: 2005;46;92